

WHAT IS CLAIMED IS:

1. A slip control system of an automatic transmission with a torque converter, comprising:

5 a lockup clutch, which is disposed between input and output elements of the torque converter, and whose engagement capacity is changeable for adjusting an actual slip-rotation speed between the input and output elements; and

10 a control unit that feedback-controls the engagement capacity, the control unit comprising:

(a) a target slip-rotation speed calculation section that estimates a target slip-rotation speed based on engine-and-vehicle operating conditions;

15 (b) a pre-compensating section that pre-compensates for the target slip-rotation speed to produce a target slip-rotation speed correction value;

20 (c) a slip-rotation speed deviation calculation section that calculates a slip-rotation speed deviation between the target slip-rotation speed correction value and the actual slip-rotation speed;

(d) a feedback compensating section that feedback-controls the engagement capacity based on the slip-rotation speed deviation to bring the actual slip-rotation speed closer to the target slip-rotation speed; and

25 (e) a dead-time processing section that compensates for the target slip-rotation speed correction value, considering a dead time of dynamic characteristics peculiar to the slip control system in the target slip-rotation speed correction value, to supply a dead-time compensated output to the
30 feedback compensating section.

2. The slip control system as claimed in claim 1, wherein:

the slip control system comprises a feedforward control system that controls the engagement capacity by open-loop control for a first time period of an automatically locked-up time period during which the lockup clutch shifts from a release state to a fully-engaged state, and a feedback control system that controls the engagement capacity by closed-loop control for a second time period of the automatically locked-up time period, and

wherein at a switching point from the open-loop control to the closed-loop control the pre-compensating section is initialized and simultaneously the dead time is reset to zero, and the dead time is variably adjusted to gradually increase from zero to a predetermined dead-time equivalent value peculiar to the slip control system with a predetermined transition time period from the switching point.

3. The slip control system as claimed in claim 2, wherein: the predetermined transition time period is determined depending on a time rate of increase in the engagement capacity controlled by open-loop control during the first time period.

4. The slip control system as claimed in claim 3, wherein: the predetermined transition time period lengthens, as the time rate of increase in the engagement capacity controlled by open-loop control increases.

5. The slip control system as claimed in claim 2, wherein: the predetermined transition time period is determined depending on the engagement capacity controlled by open-loop control during the first time period.

6. The slip control system as claimed in claim 5, wherein:
the predetermined transition time period lengthens, as
the engagement capacity controlled by open-loop control
increases.

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7. A slip control system of an automatic transmission with
a torque converter, comprising:

a lockup clutch, which is disposed between input and
output elements of the torque converter, and whose

10 engagement capacity is changeable for adjusting an actual
slip-rotation speed between the input and output elements;
and

a control unit that feedback-controls the engagement
capacity of the lock-up clutch, the control unit comprising:

15 (a) a target slip-rotation speed calculation section
that estimates a target slip-rotation speed based on engine-
and-vehicle operating conditions;

(b) a pre-compensating section that pre-compensates for
the target slip-rotation speed to produce a target slip-
20 rotation speed correction value;

(c) a slip-rotation speed deviation calculation section
that calculates a slip-rotation speed deviation between the
target slip-rotation speed correction value and the actual
slip-rotation speed;

25 (d) a feedback compensating section that feedback-
controls the engagement capacity of the lock-up clutch based
on the slip-rotation speed deviation to bring the actual
slip-rotation speed closer to the target slip-rotation
speed; and

30 (e) a dead-time processing section that compensates for
the target slip-rotation speed correction value to reflect a
dead time of dynamic characteristics peculiar to the slip
control system in the target slip-rotation speed correction

value, and supplies a dead-time compensated output to the feedback compensating section, the dead time being variable in accordance with a predetermined dead time characteristic.

5 8. The slip control system as claimed in claim 7, wherein:

the slip control system comprises a feedforward control system that controls the engagement capacity by open-loop control for a first time period of an automatically locked-up time period during which the lockup clutch shifts from a
10 release state to a fully-engaged state, and a feedback control system that controls the engagement capacity by closed-loop control for a second time period of the automatically locked-up time period, and

wherein at a switching point from the open-loop control
15 to the closed-loop control the pre-compensating section is initialized, so that the target slip-rotation speed correction value is initialized to the actual slip-rotation speed obtained at the switching point to the feedback control, and simultaneously the dead time is reset to zero,
20 and the dead time is variably adjusted to gradually increase from zero to a predetermined dead-time equivalent value peculiar to the slip control system with a predetermined transition time period from the switching point.

25 9. The slip control system as claimed in claim 8, wherein:

the predetermined transition time period is determined depending on at least one of the engagement capacity controlled by open-loop control during the first time period and a time rate of increase in the engagement capacity
30 controlled by open-loop control during the first time period.

10. The slip control system as claimed in claim 9, wherein:

the predetermined transition time period lengthens, as at least one of the engagement capacity controlled by open-loop control and the time rate of increase in the engagement capacity controlled by open-loop control increases.

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11. A slip control system of an automatic transmission with a torque converter, comprising:

a lockup clutch, which is disposed between input and output elements of the torque converter, and whose
10 engagement capacity is changeable for adjusting an actual slip-rotation speed between the input and output elements;

a slip control valve that is responsive to a signal pressure for changing a differential pressure between a lockup-clutch apply pressure and a lockup-clutch release
15 pressure;

a lockup solenoid valve that generates the signal pressure in response to a drive signal for changing the differential pressure via the slip control valve; and

a control unit that feedback-controls the engagement
20 capacity of the lock-up clutch by outputting the drive signal to the lockup solenoid valve, the control unit comprising:

(a) a target slip-rotation speed calculation section that estimates a target slip-rotation speed based on engine-
25 and-vehicle operating conditions;

(b) a pre-compensating section comprising (i) a first compensating filter that pre-compensates for the target slip-rotation speed to produce a first target slip-rotation speed correction value corresponding to a reference-model
30 output from an expression $\omega_{SLPTC1} = G_R(s) \times \omega_{SLPT}$ where ω_{SLPTC1} is the first target slip-rotation speed correction value, $G_R(s)$ is a reference model that is set as a transfer function suited to a desired response determined based on

designer's wishes, and ω_{SLPT} is the target slip-rotation speed, and (ii) a second compensating filter that pre-compensates for the target slip-rotation speed to produce a second target slip-rotation speed correction value from an

5 expression $\omega_{SLPTC2} = G_M(s) \times \omega_{SLPT}$ where $G_M(s)$ corresponds to a feed-forward compensator, which is defined by an expression $G_M(s) = G_R(s)/P(s)$, where $G_R(s)$ is the reference model and $P(s)$ is a transfer function that is obtained by modeling a lockup-clutch slip-rotation section serving as a controlled

10 system;

(c) a slip-rotation speed deviation calculation section that calculates a slip-rotation speed deviation between the target slip-rotation speed correction value and the actual slip-rotation speed;

15 (d) a feedback compensating section that feedback-controls the engagement capacity of the lock-up clutch based on the slip-rotation speed deviation to bring the actual slip-rotation speed closer to the target slip-rotation speed, the feedback compensating section comprising a feedback

20 compensator that produces a first slip-rotation speed command value suited to reduce the slip-rotation speed deviation and an adder that produces a slip-rotation speed command value by adding the first slip-rotation speed command value to the second target slip-rotation speed

25 correction value;

(e) a dead-time processing section that compensates for the first target slip-rotation speed correction value to reflect a dead time of dynamic characteristics peculiar to the slip control system in the first target slip-rotation

30 speed correction value, and supplies a dead-time compensated output to the feedback compensator, the dead time being variable in accordance with a predetermined dead time characteristic; and

(f) a drive signal determination section that determines the drive signal based on the slip-rotation speed command value.

5 12. The slip control system as claimed in claim 11, wherein:

the feedback compensator comprises a proportional-plus-integral controller that is defined by an expression $\omega_{SLPC1} = K_P \cdot \omega_{SLPER} + (K_I/s) \cdot \omega_{SLPER}$ where K_P is a proportional gain, K_I is
10 an integral gain, s is a differential operator, and ω_{SLPER} is the slip-rotation speed deviation.

13. The slip control system as claimed in claim 12, wherein:

15 the slip control system controls the engagement capacity by open-loop control for a first time period of an automatically locked-up time period during which the lockup clutch shifts from a release state to a fully-engaged state, and controls the engagement capacity by closed-loop control
20 for a second time period of the automatically locked-up time period, and

wherein at a switching point from the open-loop control to the closed-loop control the first compensating filter is initialized, so that the first target slip-rotation speed
25 correction value is initialized to the actual slip-rotation speed obtained at the switching point to the feedback control, and simultaneously the dead time is reset to zero, and the dead time is variably adjusted to gradually increase from zero to a predetermined dead-time equivalent value
30 peculiar to the slip control system with a predetermined transition time period from the switching point.

14. The slip control system as claimed in claim 13,
wherein:

the predetermined transition time period is determined
depending on at least one of the engagement capacity
5 controlled by open-loop control during the first time period
and a time rate of increase in the engagement capacity
controlled by open-loop control during the first time period.

15. The slip control system as claimed in claim 14,
10 wherein:

the predetermined transition time period lengthens, as at
least one of the engagement capacity controlled by open-loop
control and the time rate of increase in the engagement
capacity controlled by open-loop control increases.

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16. The slip control system as claimed in claim 13,
wherein:

the predetermined transition time period is determined
depending on at least one of the differential pressure
20 produced by open-loop control during the first time period
and a time rate of increase in the differential pressure
controlled by open-loop control during the first time period.

17. The slip control system as claimed in claim 16,
25 wherein:

the predetermined transition time period lengthens, as at
least one of the differential pressure produced by open-loop
control and the time rate of increase in the differential
pressure produced by open-loop control increases.

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18. A slip control system of an automatic transmission with
a torque converter, comprising:

a lockup clutch, which is disposed between input and output elements of the torque converter, and whose engagement capacity is changeable for adjusting an actual slip-rotation speed between the input and output elements;
5 and

a control unit that feedback-controls the engagement capacity, the control unit comprising:

(a) a target slip-rotation speed calculation means for estimating a target slip-rotation speed based on engine-and-
10 vehicle operating conditions;

(b) a pre-compensating means for pre-compensating for the target slip-rotation speed to produce a target slip-rotation speed correction value;

(c) a slip-rotation speed deviation calculation means
15 for calculating a slip-rotation speed deviation between the target slip-rotation speed correction value and the actual slip-rotation speed;

(d) a feedback compensating means for feedback-controlling the engagement capacity based on the slip-
20 rotation speed deviation to bring the actual slip-rotation speed closer to the target slip-rotation speed; and

(e) a dead-time processing means for compensating for the target slip-rotation speed correction value, considering a dead time of dynamic characteristics peculiar to the slip
25 control system in the target slip-rotation speed correction value, to supply a dead-time compensated output to the feedback compensating section.

19. A method of controlling a speed of relative rotation
30 between input and output elements of a lockup torque converter of an automatic transmission employing a lockup clutch, which is disposed between the input and output elements, and whose engagement capacity is changeable for

adjusting an actual slip-rotation speed between the input and output elements, the method comprising:

estimating a target slip-rotation speed based on engine-and-vehicle operating conditions;

5 pre-compensating for the target slip-rotation speed to produce a target slip-rotation speed correction value;

calculating a slip-rotation speed deviation between the target slip-rotation speed correction value and the actual slip-rotation speed;

10 feedforward-controlling the engagement capacity by open-loop control for a first time period of an automatically locked-up time period during which the lockup clutch shifts from a release state to a fully-engaged state;

feedback-controlling the engagement capacity of the
15 lock-up clutch based on the slip-rotation speed deviation to bring the actual slip-rotation speed closer to the target slip-rotation speed for a second time period of the automatically locked-up time period; and

compensating for the target slip-rotation speed
20 correction value to reflect a dead time of dynamic characteristics peculiar to a slip control system in the target slip-rotation speed correction value, the dead time being variable in accordance with a predetermined dead time characteristic, so that at a switching point from the
25 feedforward control to the feedback control the dead time is reset to zero, and that the dead time is variably adjusted to gradually increase from zero to a predetermined dead-time equivalent value peculiar to the slip control system with a predetermined transition time period from the switching
30 point.

20. The method as claimed in claim 19, wherein:

the predetermined transition time period lengthens, as at least one of the engagement capacity controlled by open-loop control and a time rate of increase in the engagement capacity controlled by open-loop control increases.